LOW TEMPERATURE THERMIONIC CONVERTERS

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FORD INSTRUMENT COMPANY
DIVISION OF SPERRY RAND CORPORATION

QUARTERLY TECHNICAL PROGRESS REPORT NO.1

DEC. 1, 1961 - MAR. 1, 1962

CONTRACT NO. AF 33(657)-7663

MARCH 1962

AERONAUTICAL SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

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FOREWORD

This report was initiated by the Static Energy Conversion Section, Headquarters, Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio. The research and development work upon which this report is based was accomplished by the Nuclear Development Division, Ford Instrument Company, Division of Sperry Rand Corporation, Long Island City, N.Y., under Air Force Contract AF33(657)-7663, "Low Temperature Thermionic Converters."

The research and development work was performed under M. Silverberg, Engineering Department Head, and L.L. Haring, Project Supervisor. The following scientists and engineers have contributed to this project: M. Cosenza, W.S. Franklin, J.J. Heyenoort, C. Kroeber, J. McInally, H. L. Phillips and G. H. Schwarz.

Mr. A. E. Wallis monitored the project for the Static Energy Conversion Section of Aeronautical Systems Division.

ABSTRACT

Fabrication and development work performed during the first three months under contract AF33(657)-7663 on the investigation of low temperature thermionic converters is presented. The fabrication work includes a high temperature electron gun envelope, improvement in emitter brazing techniques and anode cooling techniques. Cell processing and evaluation data is given as well as results of destructive and shock tests. Finally, techniques for solar and nuclear simulation are discussed.

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1.0 INTRODUCTION

Ford Instrument Company, in this quarterly report, presents the experimental and analytical data from the first quarterly period of AF contract 33(657)-7663. This investigation is a continuation of the work developed under AF contract 33(616)-7663 reported in ASD Technical Report 61-638. Under the latter contract a low temperature dispenser emitter coupled with the arc-mode method of space charge neutralization was proved to be an effective thermionic plasma diode. A metal-ceramic converter was designed utilizing concentric cup geometry. The present contract continues the design and development work on the metal-ceramic cell with the effort extended to include both solar and nuclear heat source applications.

The development work performed during the period covered by this report concerns improvements in converter fabrication, vacuum processing and evaluation of cell performance including some destructive testing, and study of heat source simulation techniques. During this quarter valuable information was obtained regarding the materials capability and emission properties of the design converter.

The major effort during the second quarter will be directed toward further improvement of the output performance of the metal-ceramic devices.

2.0 CONVERTER FABRICATION

2.1 High Temperature Electron Gun Assembly

The present cell bake-out temperature is limited to 450°C due to the 7052 gun envelope. It was decided to design an electron gun envelope which would be capable of higher bake-out temperatures. Such temperatures would reduce outgassing and the possibility of cathode poisoning over longer lifetimes. Three envelope materials were considered: quartz, alumino-silicates, and metal-ceramics. Of these, the latter was the most attractive because of the availability of the materials and the presently established processing methods.

A prototype unit was fabricated in order to anticipate the various metal joining problems. The envelope of the unit consists of a kovar cup having the same diameter as the ceramic cell. Three holes are bored into this base cup, to receive, (1) the OFHC copper pumping tubulation, (2) the sapphire sighting window tube,(3) the ceramic-pin assembly. The sighting window tube was brazed to the base cup using an RF radiant oven arrangement. The remainder of the metal-to-metal joints were accomplished by heliarc welding. All joints successfully passed leak checking by the helium mass spectrometer (10^{-10}) std. cc/sec.). The prototype unit is shown in Figures 1 and 2.

Further investigations will be carried on in this area of the high temperature assembly. During the next quarter, installation of metallized sapphire windows will be accomplished, along with methods of incorporating residual ion pumps and/or getters capable of the high temperature bakeout. High temperature bake-out ovens flushed with inert gas

will be completed and available during the next quarter for their processing. All-metal vacuum maniforld designs incorporating quick metal disconnects are presently being installed.

2.2 Emitter Brazing Techniques

Two problems have been investigated in this area. First, it was found that there was a non-uniform thermal bond between the emitter and the bottom of the cup. This was evidenced by the variation in brightness of color over the area when at operating temperature. Destructive tests confirmed this hypothesis. Figure 3 shows a cross section where the braze had adhered only at the left side of the cup. This occurred because of the difficulty of obtaining a perfect match of surfaces at the brazing temperature (1375°C). Improvements were made in the flatness of the cold cups and a method was devised for applying variable pressure during the brazing operation. The most recent brazes have achieved almost 100% bonding as evidenced in the cross section in Figure 4.

During the brazing operation using the variable pressure technique, it was found necessary to elevate the power to the R.F. furnace because of the increased conductive heat loss incurred. This gave rise to a second problem. Some of the cups brazed in this manner were found to leak at the radius. An intensive investigation showed that the cause of the trouble was an instantaneous braze attack at the molybdenum as a result of the uneven heating of the cup. A temperature profile taken during brazing indicated that the regions of the highest temperature

showed the greatest attack. A number of changes were made to improve the temperature uniformity of the cup during brazing, with the result that this instantaneous attack is not present in the latest emitter to cup brazes.

Figures 5-a and 5-b show photomicrographs of the emitter-braze-molybdenum boundaries. It is interesting to note that the braze penetration is quite localized. This is encouraging since the poisoning effect upon the emitter is probably related to the depth of penetration. As life data developed, other photomicrographs were taken to determine long term migration at operating temperature (1200°C). See section 3.3.

A demountable vacuum system is being constructed to investigate the possibility of thermal pre-testing of emitter cup assemblies. This coupled with subsequent helium mass spectrometer leak checking should prove the sub-assemblies soundness prior to final assembly.

2.3 Laboratory Methods of Anode Cooling

During this quarter, effort has been expended to investigate and improve the anode cooling techniques for cell evaluation. Several anode flush/coolers utilizing argon were tried. The various geometries are shown in Figure 6. Thermocouple measurements on the anode showed two non-uniformities. First, in some flush/cooler designs the sides of the anode ran below 200°C ambient when attempting to cool the bottom of the cup. Second, the variation of temperature over the bottom of the

cup from center to the knuckle radius was high. With a centered flush tube, the knuckle radius temperature could be still high enough for appreciable back emission while the center was cooled well below this level.

Improved anode temperature uniformity was obtained by using a gas cooling loop shaped in the form of a pancake helix (extreme left in Figure 6). This helix is then inserted into the anode cup bottom. To improve the conductive heat transfer between the helix and the cup bottom it was necessary to introduce a metal (molybdenum or copper) powder. In order to utilize such a technique it was required to rearrange the gravity orientation of the cell, which in turn necessitated a revamp of the cesium bulb temperature control. Some limited thermocouple testing with a non-cesium cell, TC159, showed that the technique is promising. In future testing, a liquid metal may be substituted for the metal powder. This will be useful in those cases utilizing DC testing where the electron heating of the anode is considerable.

3.0 CELL PROCESSING AND EVALUATION

3.1 Vacuum Processing

Nine metal-ceramic cells have been vacuum processed during the quarter. One of the cells, TC152, was used to obtain thermal cycling data. This was accomplished by alternately attaching and disconnecting the electron gun high voltage supply. It was cycled 20 times during 113 hours with warm-up and cool-down periods of about one minute. An ion pressure gauge measurement showed that absolutely no deterioration in vacuum had occurred.

In some of the early cells with nominal cup bottom thicknesses of 6 mils, some minute cracking and porousity occurred at thermal lifetimes approximating 100 hours. In the latest units, the thickness has been increased to 10 mils and considerable improvement has resulted. Even thicker molybdenum cup bottom are being fabricated in order to take advantage of the increased strength reliability. In addition, material substitution is also being carried on via a parallel effort (section 3.3).

The vacuum emission of the cells is monitored during pumping to determine the degree of cathode activation prior to seal-off. These values are listed in Table I. As the voltage that can be applied to the device is limited, it is known that these values lie in the space charge limited region. The estimated saturation values are approximately twice the listed values. This has been correlated by work function measurements at reduced temperatures.

TABLE II CURRENT-VOLTAGE CHARACTERISTICS

Cell 160		Cell 164		Cell 166	
Cathode 1200°C Cs 210°C		Cathode 1100°C Cs 219°C Anode 473°C		Cathode 1160°C Cs 200°C Anode 367°C	
Volts	Amperes	Volts	Amperes	Volts	Amperes
-0.8	0.3	-0.6	0	- .8	1
-0.7	0.4	-0.4	0.2	- .6	2
-0.6	0.5	-0.2	0.5	- .4	3
-0.5	0.8	-0	1.0	- .2	4.5
-0.4	1.1	+0.2	2.0	0	7.5
-0.3	1.6	+0.4	4.0	+1.0	20.0
-0.2	3.5	+0.6	6.5	+2.0	45.0
-0.1	6.0	+0.8	9.0	+3.0	80.0
-0	8.0	+1.0	12.0		
		+2.0	27.0		

3.2 Converter Performance

Current-voltage characteristics of two devices evaluated during this period are given in Table II. Both sets of data were taken under pulsed conditions.

Initial evaluation of the TC160 data indicated that there was a possibility of back emission from portions of the anode which were in the incandescent region. The steep slope with poor current at thermionic voltage and high current in the passive voltage region were indicative of such emission.

The second cell, TC164, used an improved anode temperature controller (473°C), described in section 2.3. The performance characteristics, were seen to be similar to the previous cells. As the possibility of serious back emission was removed, other causes for the device performance were considered. Further evaluation of the data indicated that the cathode was in a partially poisoned condition, and that the available emission was primarily from the cathode support areas. Further verification of cathode poisoning of the sealed-off devices is being pursued. The extension of pressure build-up tests to the devices while on the vacuum system will be instituted. Periodic vacuum emission checks during testing will further substantiate the effect of a sealed-off cesium environment. While the above methods will document the phenomenon, the improvement of this condition has already been anticipated by the development of the high temperature bake-out design discussed in section 2.1.

TABLE I VACUUM EMISSION

Cell	Temp. °C	Current Amperes	Voltage Volts	Comments
159	1170	8	4500	Partially poisoned Cathode, 6 mil cup
160	1170	20	5500	Completely processed, 6 mil cup
161	1170	15	5250	Elevated temperature run at 1270°C caused migration through 6 mil cup
162	1170	15	5250	Small crack developed in vacuum manifold. Unit repumped
	1100	11.5	4500	Reprocessed cell, 6 mil cup
163	1100	11	4500	Used Amperex TP101 titanium getter pump on the electron gun envelope 6 mil cup
164	1100	15	4500	10 mil cup
165	1170	15	4500	10 mil cup
166	1170	16	5250	10 mil cup

Additional work has been done to reduce the amount of cell material outgassing. During all elevated temperature assembly work, the unit has been kept continuously in a reducing atmosphere to eliminate any oxidation of surfaces. Pure cesium high temperature (quartz) frangible pellets are presently being developed to replace the cesium chromate-silicon pellet. The latter generates some gas during the high temperature period when it is reduced to pure cesium.

In addition, other causes for the difference in device performance relative to glass cell construction are presently being considered. These relate to the concentric cup geometry itself. The question of auxiliary discharges along the cup sides and their limitation of the main discharge is one postulation. The other involves an altered energy balance to the plasma region as a result of the change in the surface-volume arrangement.

The auxiliary discharge limitation concept is being pursued along a number of avenues. Emission experiments are being undertaken with the present concentric cup geometry devices in order to differentiate between cathode and support emission. Runs at reduced cesium pressure will be taken in order to reduce the effect of support emission. Furthermore, the ratio of spacing for the main discharge relative to the support spacing will be reduced in a few of the succeeding cells. In this manner, improved ignition of the main discharge should result. In addition, another design modification is being considered for a limited run of cells. A substitution

of a purely planar cathode support assembly instead of the cup geometry will be tried. The support diaphram will be of tungsten and other alloyed refractory metals so as to improve its resistance to granular growth at operating temperature.

3.3 Destructive Testing

In a number of cells a slight darkening of the electron gun envelope took place prior to any cesium testing. This was verified by spectographic and chemical analysis to be the nickel braze material which had migrated through the bottom of the 6 mil cathode cup. In all but the 10 mil cup, cesium vapor penetration during the initial phase of testing caused the eventual breakdown of the electron gun bombardment technique.

In view of this it was decided to proceed with destructive testing of these units to analyze in detail the migration phenomena. Photomicrographs were taken of a sample braze which was not subjected to any activation proceedures. This braze cross section is shown in Figures 7a, b, and c, for increasing magnifications. The cross section is of the tungsten cathode brazed to molybdenum cup. The impregnated tungsten (Philips Type B) is on top with the molybdenum cup on the bottom.

Following this, cell TC162 which had been subjected to a thermal lifetime of 80 hours was cut open and photomicrographs were taken of the braze cross section (6 mil cup). This tungsten on molybdenum cross section is shown in Figures 8a, b,c,d, and e. Figure 8a can be compared with Figure 7a, of the same magnification. This comparison shows development of grain growth in the molybdenum after 80 hours. Figures 8b, c, and d,

are magnification of 400 times of a continuous cross section (the same as shown in 8a). Finally, Figure 8e was produced with deeper etching to show the penetration of the braze into the molybdenum.

Further photomicrograph comparisons will be made relative to various environmental conditions. Controlled experiments are presently being planned with numerous dummy specimens. The specimens will be brazed with varied techniques and materials and placed in a vacuum oven at 1100°C. Photomicrographs at various life times will be taken to investigate the improvement of intergranular penetration.

Some of the more clearly defined improvements are now being undertaken in subsequent cell fabrication. These are as follows:

(1) Increased uniformity of brazing temperature (1375°C)

(2) Reduced amounts of brazing material

(3) Thicker molybdenum cup bottoms

(4) No prior acid etching of cup bottoms.

In addition to the short range solutions above, long range considerations which involve change of materials are being pursued. Tungsten and other alloy cups are being evaluated in order to take advantage of their similarity of thermal expansion and their reduced crystallization phenomena. As tungsten forms much less easily than molybdenum, the more ductile tungsten alloys are also being evaluated. A number of fabrication techniques are being pursued, spinning, drawing, machining, eloxing of

homogeneous pieces along with heliarc and beam welding of separate disks and tubing.

3.4 Shock Testing

A metal-ceramic subassembly and complete metal-ceramic cell were each successfully subjected to shock and vibration tests. The two specimens are shown in Figures 9 and 10. Each specimen was subjected to one impact shock each of 2g's, 4g's, 6g's and 8g's, and 3 impact shocks of 10g's, each shock impulse having a time duration of 11 ± 1 milliseconds. The shock was applied laterally and longitudinally. The specimens did not suffer damage as verified by checking initial leak rate versus final leak rate.

Vibration Testing - With the specimens in both lateral and longitudinal positions they were separately vibrated between 20 and 2000 cps and returned to 20 cps. The sweep time was 20 minutes. The operation was repeated for applied accellerations of 4g's, 8g's, 12g's, 16g's, and 20g's for a total test run of five 20 minute sweeps in both planes. After each sweep the specimen was removed from the table and visually inspected for mechanical failures. There was no deterioration in cell integrity.

4.0 HEAT SOURCE APPLICATIONS

Two aerospace applications have been proposed for utilizing the low temperature thermionic converters developed under contract AF33(616)-7663. The applications are solar heat and nuclear heat. Some of the characteristics of the converter which show promise for each application are given below.

The low temperature concept has been integrated into a concentric cup design which is particularly suitable for placing in a solar cavity type generator. A further advantage of the low temperature operation is that it reduces the requirements on the solar collector design. If the concentration ratio required is reduced, then rigidity and therefore weight is reduced. Re-radiation losses at the cavity are reduced by operating at a lower temperature.

With respect to the reactor radiator concept, low temperature arc-mode converters are the only possible cesium thermionic devices which are competible. Present technology limits the feasibility of temperatures of reactor radiator loops to the region of 1150°C. Fortunately, our devices have useful output power in these regions. Higher temperature operation would require extensive reactor materials development. The cylindrical geometry should not be inherently more difficult than parallel plate configurations, however, it will be advantageous to utilize parallel plate sections in multi-polygon arrangements to approximate a cylindrical

surface. This will reduce the development time since the parallel plate concept is considerable further along in design and evaluation.

In brief, the low temperature arc-mode diodes are not only feasible for such applications, but can be expected to alleviate many of the heat source integration problems common to higher temperature units.

4.1 Solar Simulation

Three basic techniques have been considered for utilizing the Strong arc-image furnace as a solar simulator.

(1) Vacuum enclosure.

(2) Inert gas protective atmosphere.

(3) Protective coating in air.

Work has been performed on evaluating the pertinent properties of envelope materials for the vacuum enclosure method. Transmission, absorption and thermal shock were investigated. As a result of our experiments, fused silica and vycor appear far supperior to the hard glass family. A preliminary envelope design is progressing. Figure 11 shows a vacuum enclosure experiment using a molybdenum target disk. Molybdenum porosity and diffusivity is not a limiting factor in the vacuum enclosure technique to the solar test life of the converter.

4.2 Nuclear Simulation

Four general types of cylindrical cell design were considered for nuclear heat simulation. The four possibilities are: a complete cylinder of revolution; a half cylinder of revolution which would be used in pairs; a parallel plate unit with a cylindrical to flat transition piece; a number of cup units with cylindrically curved bottoms. These designs were weighed as to material availability, time and cost of fabrication.

Work has been done on designing a 7/16" inside diameter cylinder heat source. The presently envisioned prototype would consist of a 1" cube of refractory metal (tungsten or molybdenum) with a 7/16" hole drilled along on its axis. The present concentric cup converter would be brazed on to one of its faces while the others will be covered with insulation. The heat source would utilize electron bombardment with an emitter positioned along the cylinder axis. The whole unit would be placed into a vacuum bell jar.

Some preliminary thermal evaluation has been performed and the temperature distribution of such a constant heat flux source was compared to a constant temperature source. As the thermal conductivity of the block is quite good the effect on temperature distribution is not expected to be serious.

5.0 SECOND QUARTER PLANNING

The major effort of the second quarter will be expended in the direction of improving converter performance. The high temperature electron gun envelope will be completed. Tungsten and other alloy cups will be fabricated, and tungsten and other alloy planar assemblies will be used in prototype experiments to observe the expected improvement of geometry changes on emission characteristics.

In addition, effort will continue on the following items:

(1) Design and fabrication of nuclear oriented cells and their electrical heat source simulation.

(2) Fabrication and testing of solar oriented cells using electrical heat and the arc-image furnace.

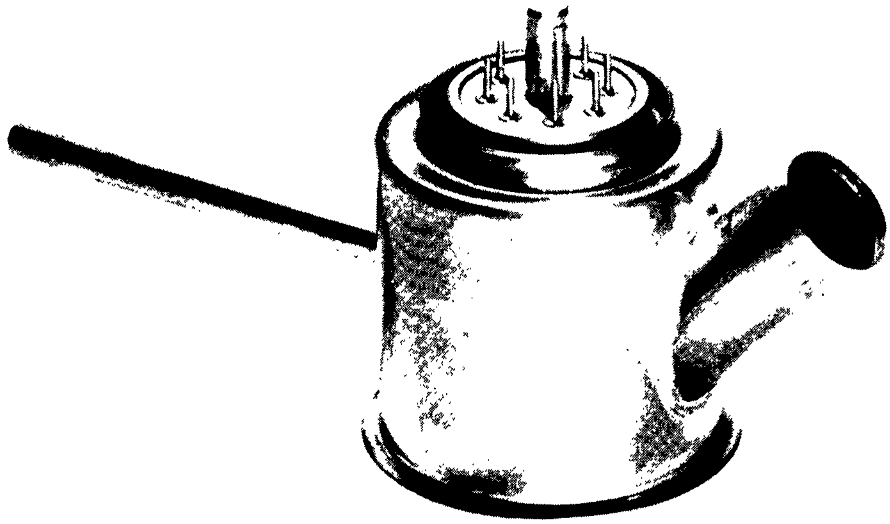


FIG. 1a ELECTRON GUN ASSEMBLY - BASE UNIT

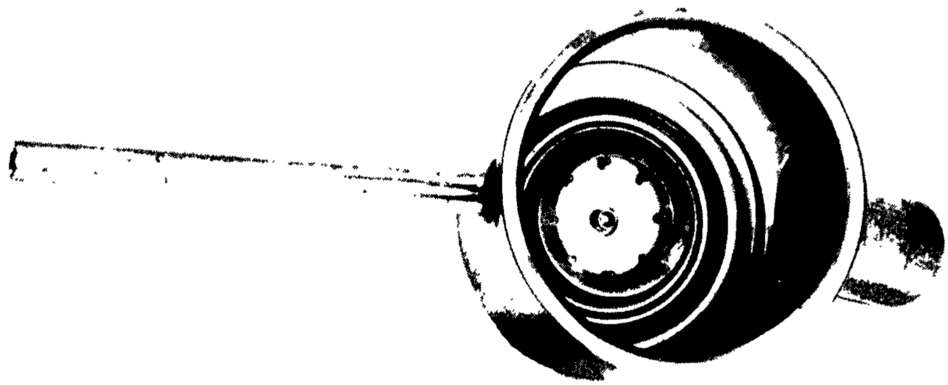


FIG. 1b ELECTRON GUN ASSEMBLY - BASE UNIT

FIG. 2 ELECTRON GUN ASSEMBLY - BASE UNIT ATTACHED TO CONVERTER

FIG. 3 CROSS SECTION SHOWING PARTIALLY BRAZED CATHODE

FIG. 4 CROSS SECTION SHOWING FULLY BRAZED CATHODE

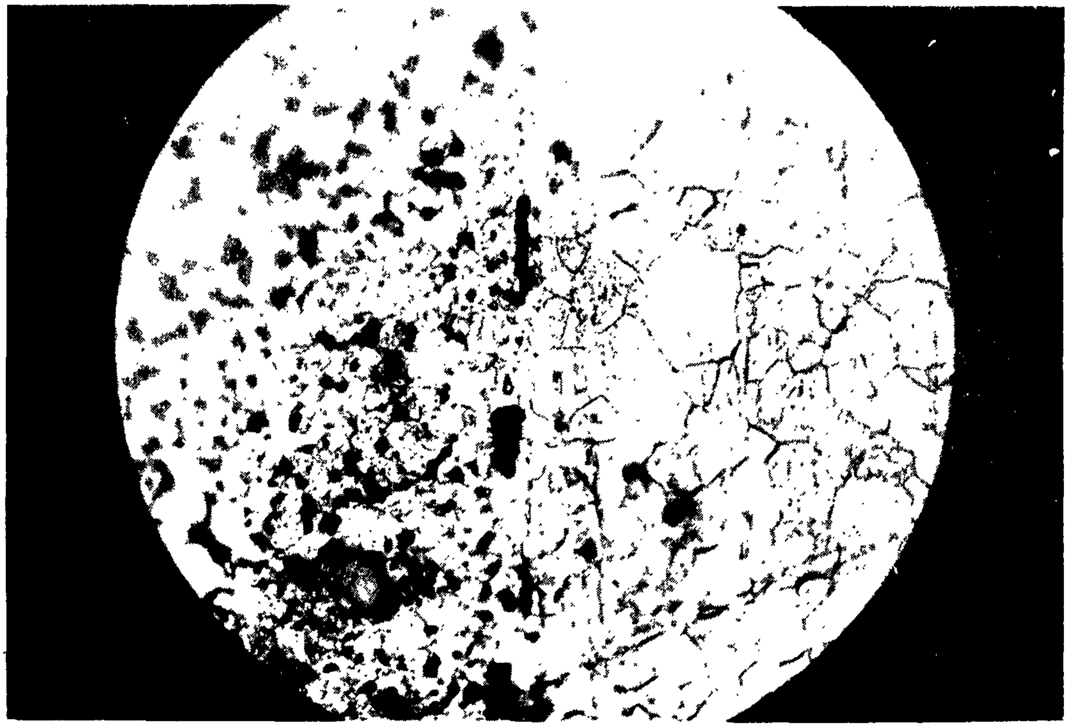


FIG. 5b NEWLY BRAZED CATHODE

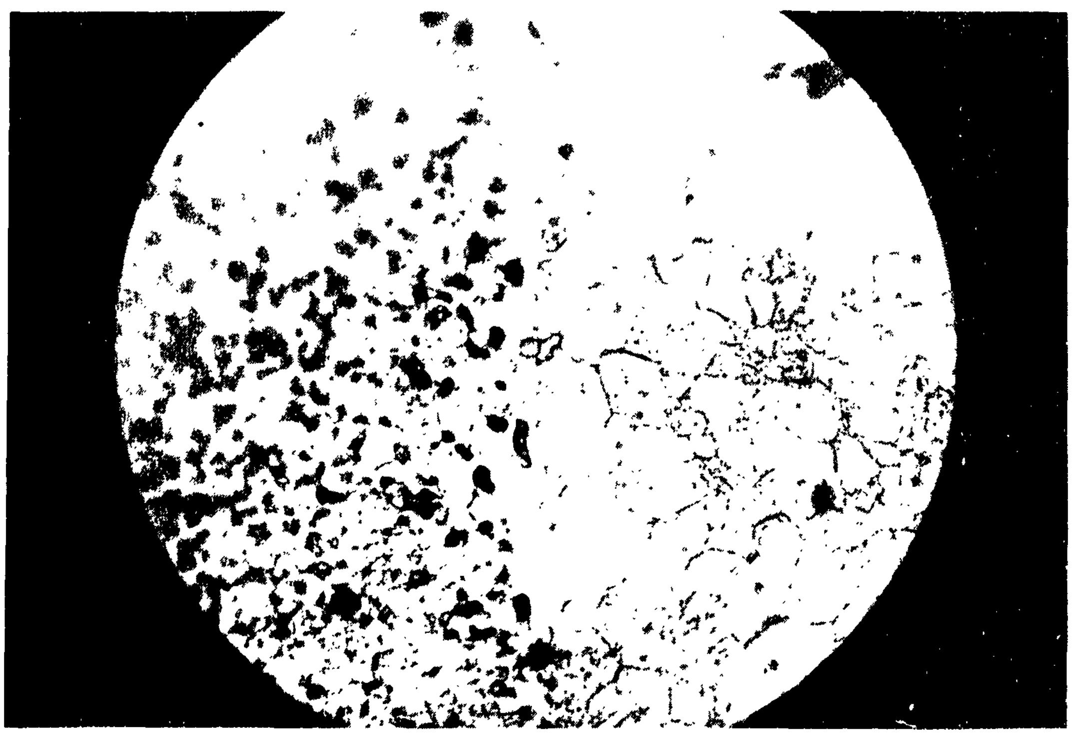


FIG. 5a NEWLY BRAZED CATHODE

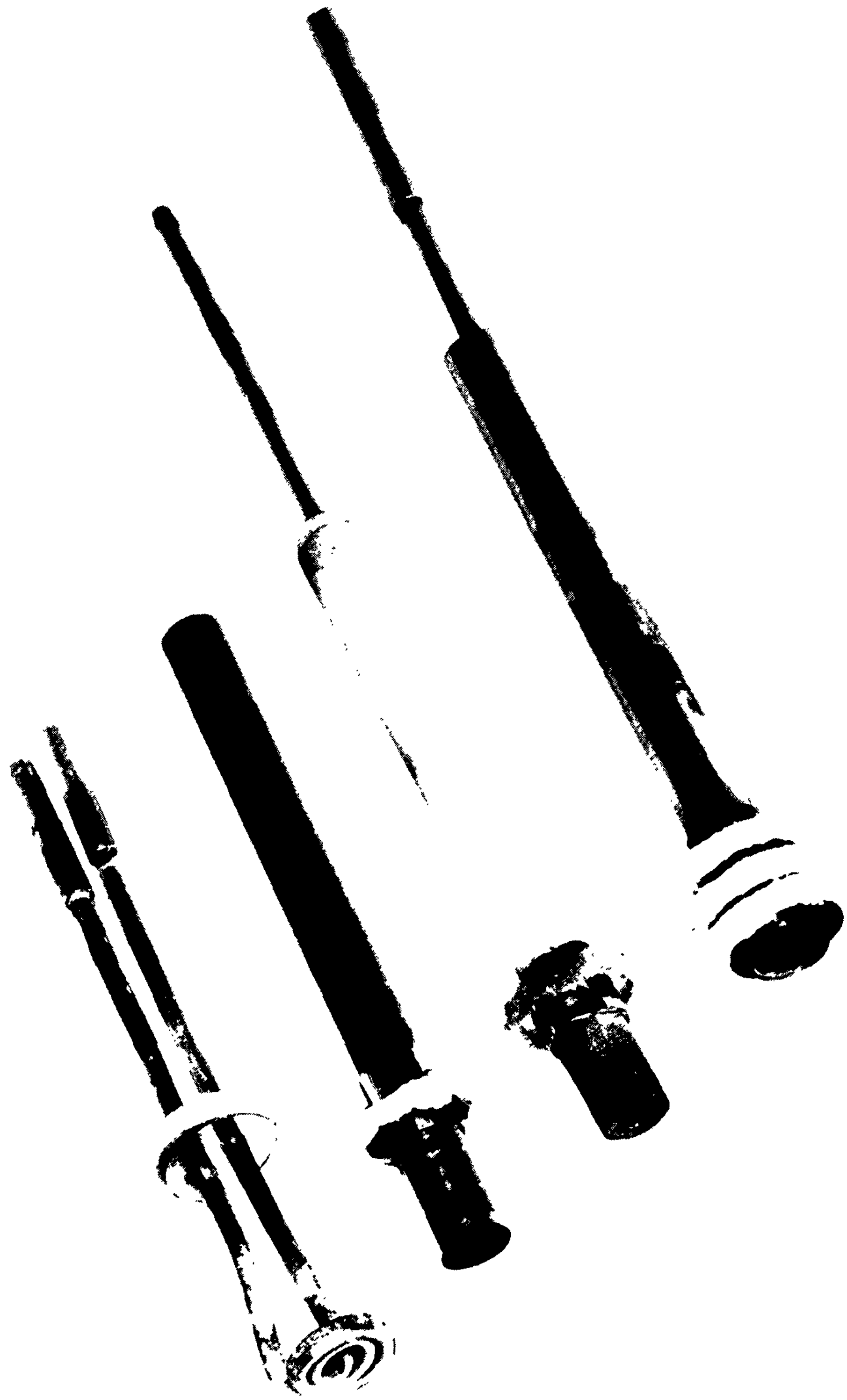


FIG. 6 VARIOUS ANODE FLUSH/COOLERS UTILIZING ARGON

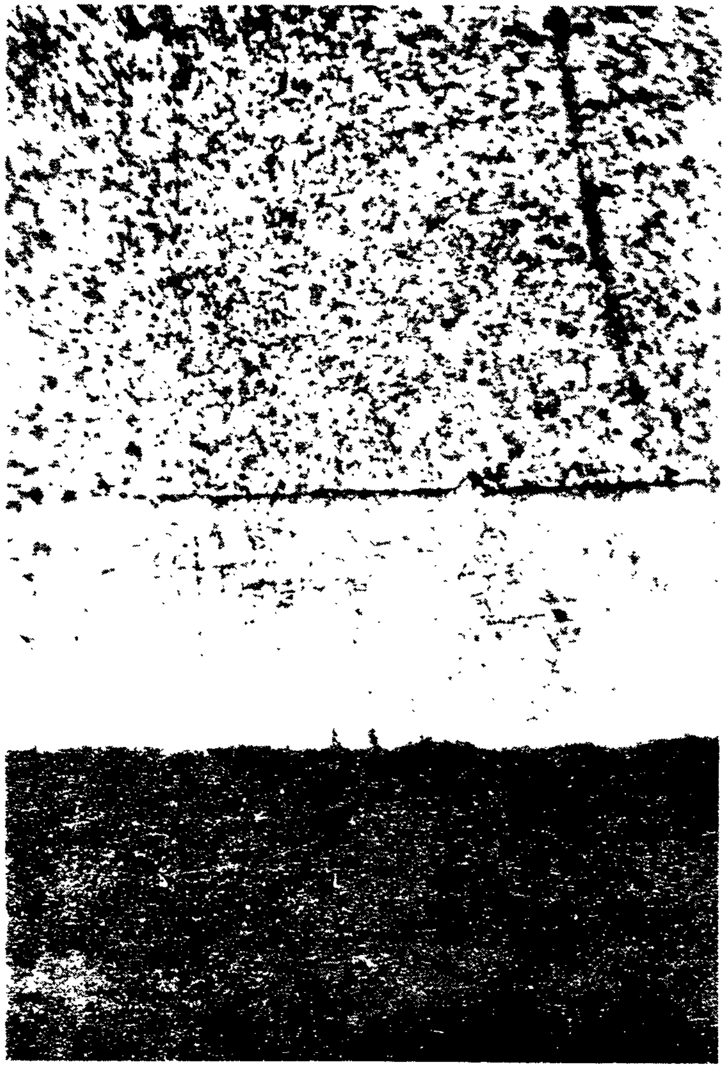
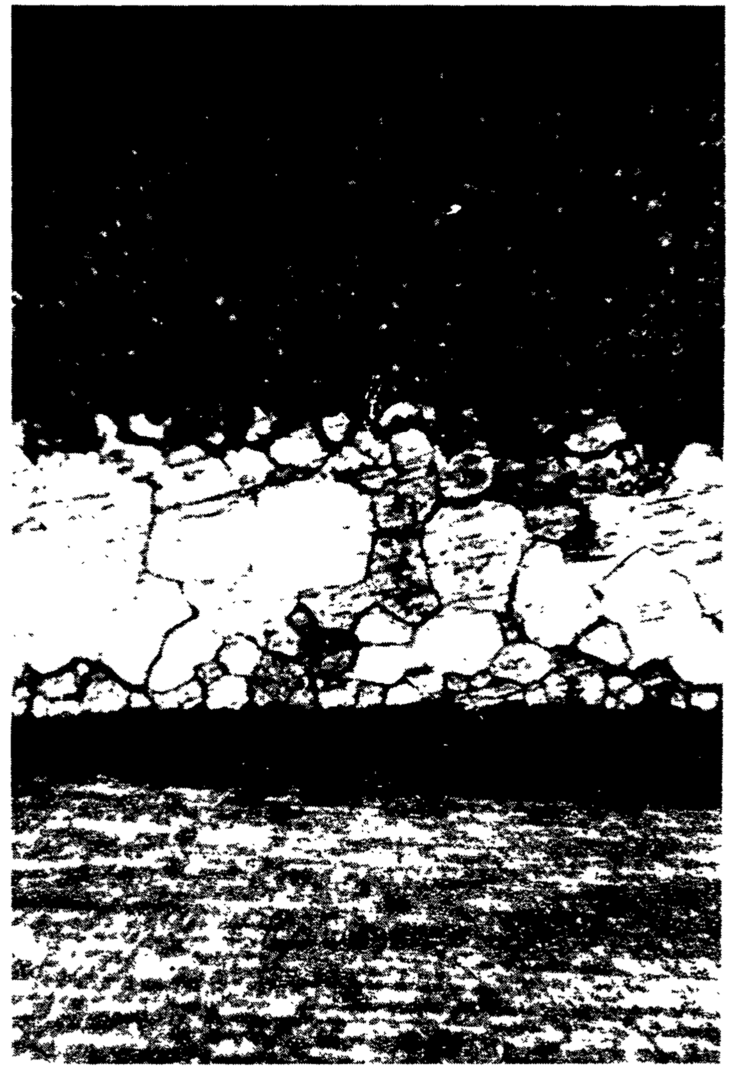


FIG. 7a SAMPLE BEFORE ACTIVATION MAG. 150 X



8a FIG. 8a CELL 162 AFTER ACTIVATION MAG. 150 X

FIG. 7b SAMPLE BEFORE ACTIVATION MAG. 300 X

FIG. 7c SAMPLE BEFORE ACTIVATION MAG. 400 X

FIG. 8b CELL 162 AFTER ACTIVATION MAG. 400 X

FIG. 8c CELL 162 AFTER ACTIVATION MAG. 400 X

FIG. 8d CELL 162 AFTER ACTIVATION MAG. 400 X

FIG. 8e CELL 162 AFTER ACTIVATION MAG. 400 X

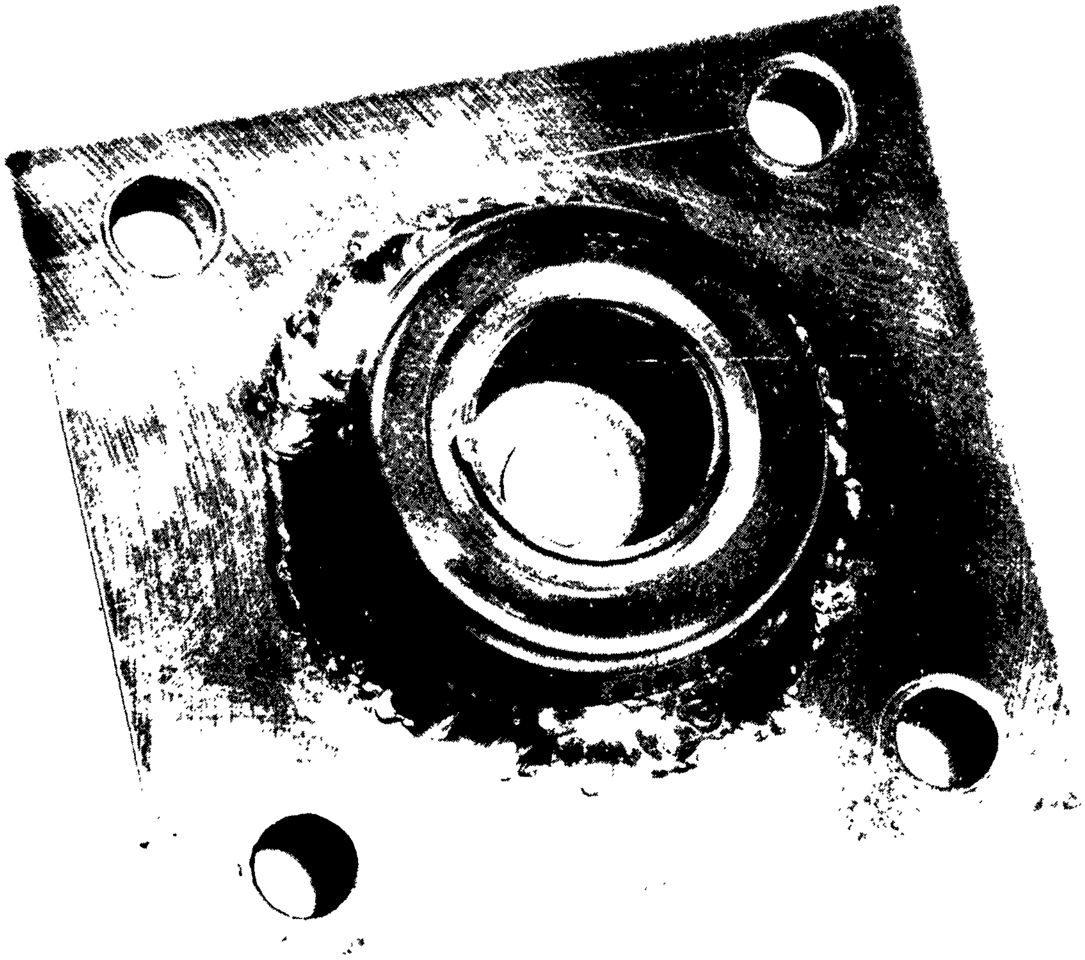


FIG. 9 CATHODE CUP WITH FLANGE AFTER SHOCK TEST

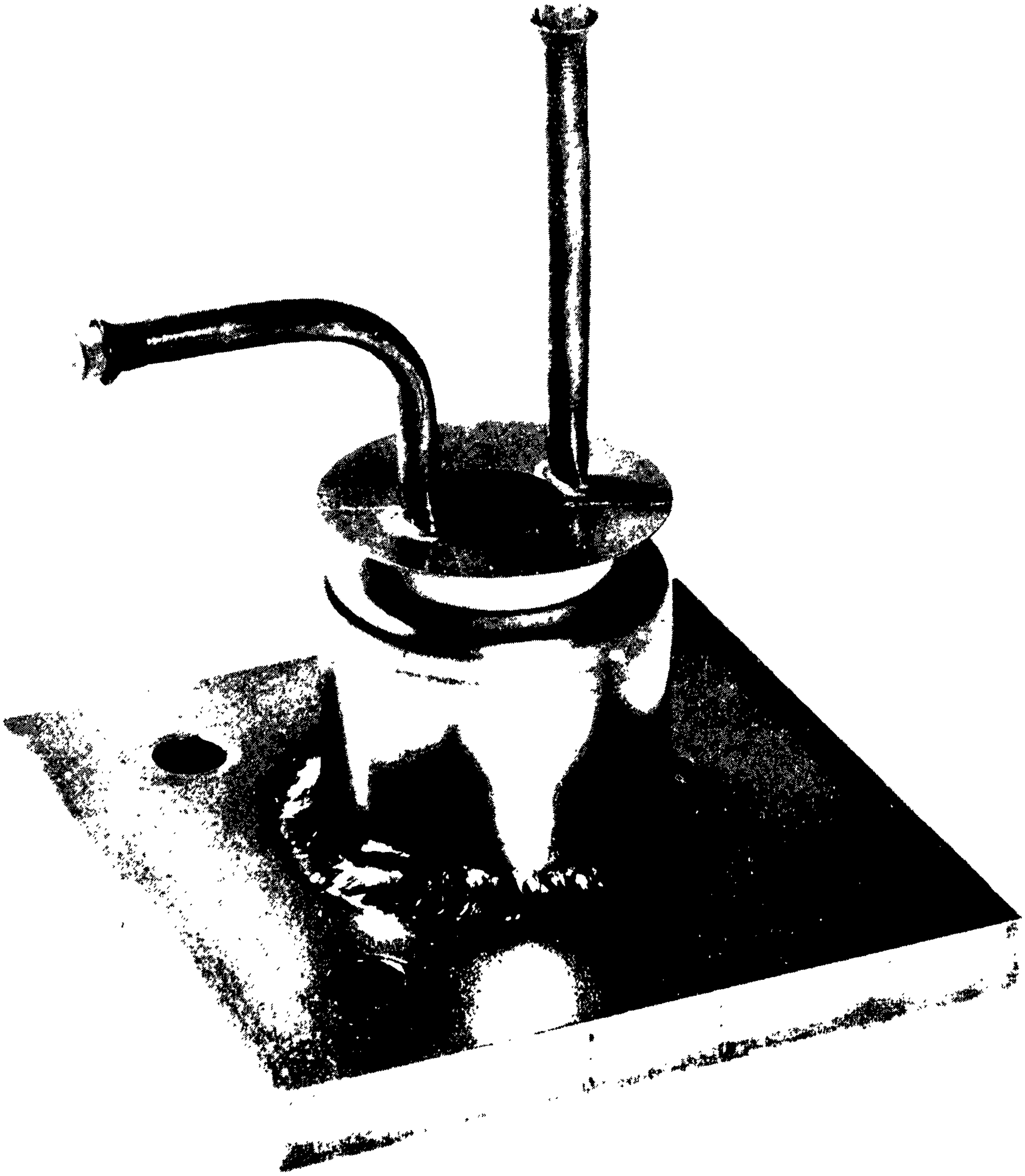


FIG. 10 COMPLETE CONVERTER ASSEMBLY AFTER SHOCK TEST

FIG. 11 SOLAR VACUUM EXPERIMENT WITH MOLYBDENUM TARGET DISK